Population of Analogs of Excited States in the 56Fe(p,n)56CO Reaction at Ep=28-, 32- and 35-MeV

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journal or publication title	CYRIC annual report
volume	1980
page range	48-51
year	1980
URL	http://hdl.handle.net/10097/48566

V. 4 Population of Analogs of Excited States in the $^{56}Fe(p,n)^{56}Co$ reaction at E_p =28-, 32- and 35-MeV

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The (p,n) and (^{3}He,t) charge-exchange reactions have been widely investigated for their utility as a spectroscopic tool and for the studies of reaction mechanism and isospin dependent nuclear reactions. A significant amount of information for the reaction mechanism to populate an analog of the excited state has been accumulated. Madsen et al.[1] have reported that the two-step processes dominate the excited 2^+ analog transitions, and given a successful explanation for the transition strength in the $^{56}Fe(p,n)^{56}Co^*$ (2^+ analog) reaction at E_p = 18 MeV. A systematic study by Livermore group[2-4], supports that the two-step process proceeds via (p,p') followed by charge exchange and charge exchange followed by (n,n'). Our recent study on cadmium isotopes[5] suggests that the coupled-channel calculation including the direct process with $\beta_2^{(1)}$ $\beta_2^{(0)}$, where $\beta_2^{(1)}$ denotes the isovector deformation parameter and $\beta_2^{(0)}$ isoscalar one, explains successfully the 2^+ analog cross section. In this report, prominent peaks in the $^{56}Fe(p,n)^{56}Co$ spectrum are assigned to be the 0^+, 2^+, 4^+ and 3^- analog states, their angular distributions of the differential cross section are explained by the coupled-channel calculations which include a important contribution from the direct process, and finally will be emphasized the utility of the (p,n) reaction as a spectroscopic tool.

The analogs of the excited states in the $^{56}Fe(p,n)^{56}Co$ reaction has been examined at the proton energies of 28, 32 and 35 MeV. Proton beams for this experiment were provided by the AVF cyclotron at Cyclotron and Radioisotope Center, Tohoku University, and emitted neutrons were analyzed by the time-of-flight facilities[6] with a flight path of 24.6 m. To avoid overlap of neutron spectra, a sinusoidal beam chopper was used at a chopping rate of 1 to 12; one beam burst in twelve ones is allowed to pass through a pair of slits located at a distance of 0.9 m after the chopper. The target was prepared by rolling of metallic iron, enriched to 99.9 %, and thickness was 6.1 mg/cm^2.

A neutron spectrum translated from the time-of-flight spectrum, and corrected by detection efficiencies is presented in fig. 1, a level diagram being the strongly populated collective states in the parent nucleus ^{56}Fe by the (p,p') and the (n,n') reactions.[7] Fine lines in fig. 1 suggest analog relations between levels in target (parent) and the residual nucleus ^{56}Co. An error for the excitation energy is estimated to be less than 30 keV except for the case of the ground analog which has been found to be a doublet.[8] Experimental angular distribution for emitted neutrons leading to the IAS and the 2^+ analog of the excited state in the $^{56}Fe(p,n)^{56}Co$ reaction at E_p = 28 MeV are shown in fig. 2, together with the theoretical predictions by the optical model analysis for IAS and the coupled channel calculations by the code CHUCK[9] for the 2^+ analog. Optical parameters were taken from Carlson et al.[10] The form factor of interacting potential for 2^+ analog is expressed as

$$\Delta U = [-R\ \beta_2^{(0)} \frac{\delta}{\delta r} U^{(0)} + {}_2^{(1)} \frac{\delta}{\delta r} U^{(1)}] ,$$

where β and U mean the deformation parameter and optical potential, respectively, and indices (0) denotes isoscalar part and (1) does isovector one. In the present analysis, two sort of calculation have been carried out; with $\beta_2^{(0)} = \beta_2^{(1)}$ as shown by a dashed line in fig. 2 and with $\beta_2^{(1)} = 2\beta_2^{(0)}$ presented by a solid line.

Figure 3 demonstrates experimental angular distributions for emitted neutrons leading to the 3.55- (ground analog), 4.415- (2^+ analog), 5.339- (4^+ analog) and 7.986-MeV (3^-analog) states. It should be noticed that angular distributions exhibits the characteristic patterns along with the values of transfer L; $J^\pi = L^{(-)L}$. A spin-parity assignment for a prominent peak in the (p,n) spectrum can be made successfully taking into account the level diagram of the parent nucleus. Further analyses for the 3^- and 4^+ analog states are in progress.

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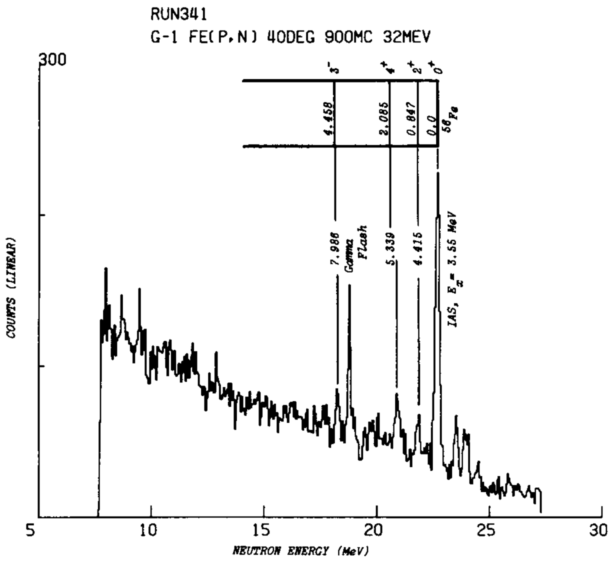

Fig. 1. Energy spectrum of the $^{56}Fe(p,n)^{56}Co$ reaction translated from the time-of-flight spectrum at a proton energy of 32 MeV and with a flight path of 24.6 m. The ^{56}Fe levels, which are strongly populated by the (p,p') and/or (n,n') reactions.

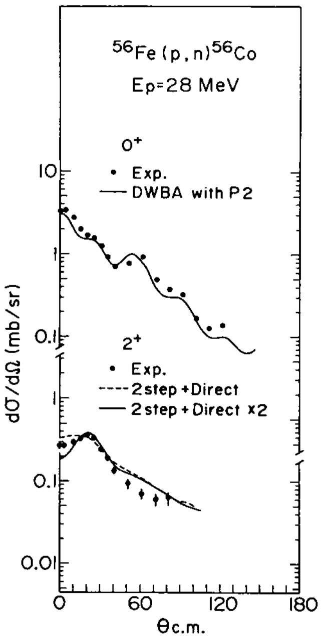

Fig. 2. Angular distributions of the IAS and the 2^{+} analog at E_p = 28 MeV. Lines are theoretical predictions. See text for the meanings of lines.

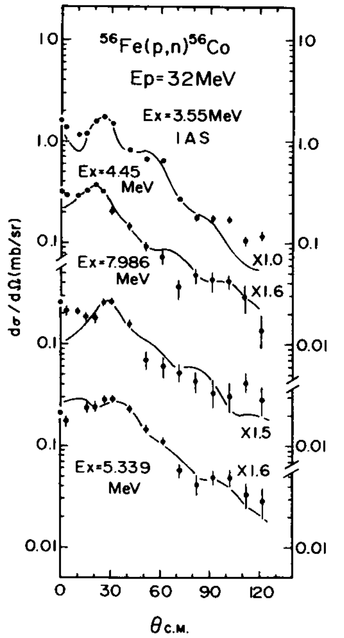

Fig. 3. Experimental angular distributions of emitted neutrons leading to the 3.55- (IAS), 4.415- (2^+ analog), 5.339 (4^+ analog) and 7.986-MeV (3^- analog) states.